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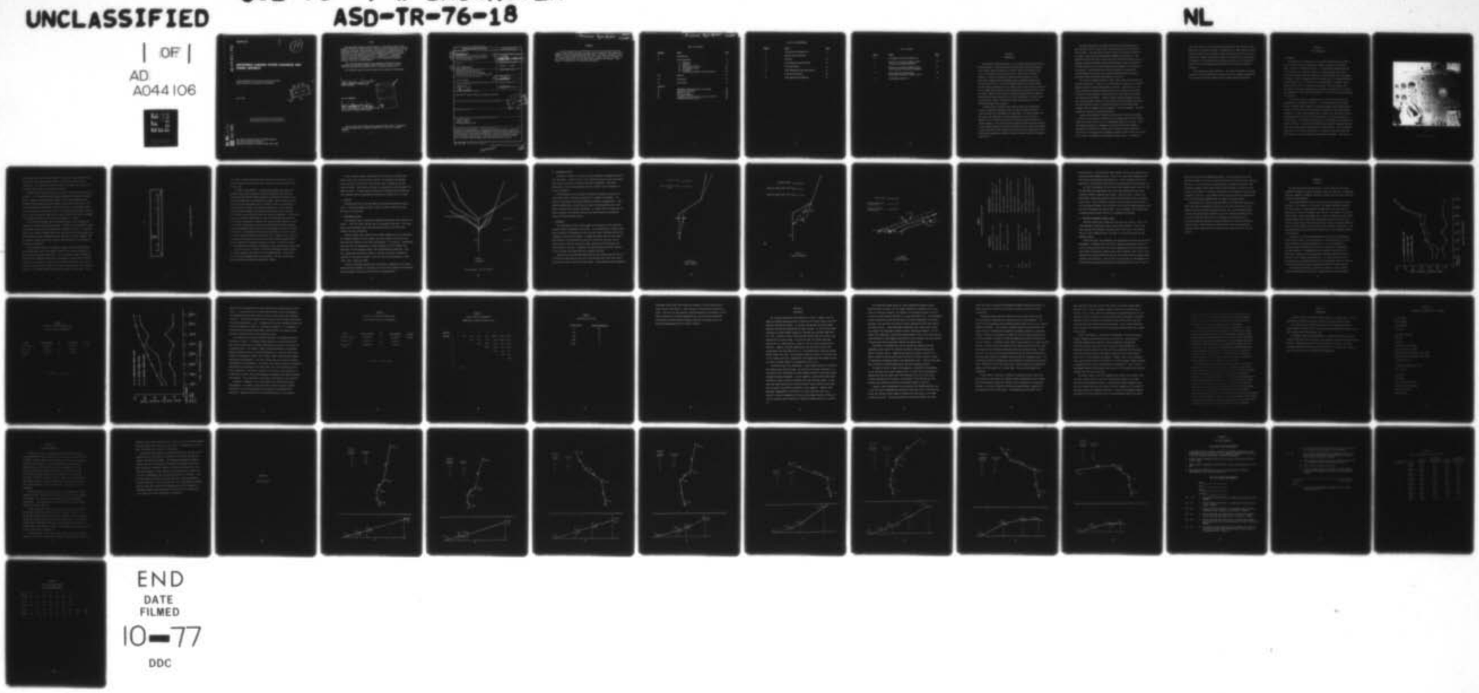

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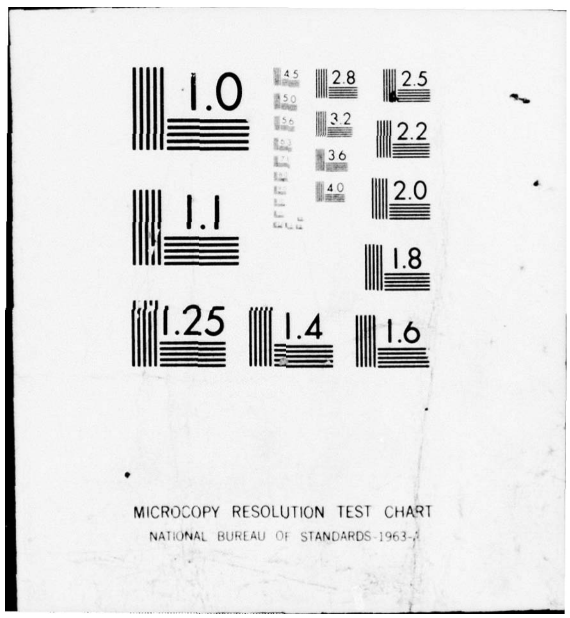
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MICROWAVE LANDING SYSTEM UTILIZATION AND DIGITAL AVIONICS

CREW EQUIPMENT AND HUMAN FACTORS DIVISION
DIRECTORATE OF EQUIPMENT ENGINEERING

JULY 1976

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AIR FORCE AERONAUTICAL SYSTEMS DIVISION
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The study had two objectives. It was designed to assess how well a pilot could determine if he were flying the intended MLS approach path and to examine how profile design affected tracking performance. The study revealed that the pilot was better able to evaluate his location with respect to the nominal approach path horizontally than vertically. Profiles with short final approach legs (2n.m.) and high intercept angles (60°) were most difficult to fly.

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FOREWORD

The work reported was performed at the Crew Station Design Facility (CSDF), Crew Station, Escape, and Human Factors Branch of the Aeronautical Systems Division, Wright-Patterson AFB, Ohio. The effort covered in this report was accomplished during the period 15 August through 1 November 75. Mr. Richard Geiselhart was the CSDF director during the program. Capt. Thomas W. Showalter was the contributing author.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

SECTION I

INTRODUCTION

The Microwave Landing System (MLS) is an instrument landing system currently under development. The MLS ground station electronically defines each waypoint in the terminal approach airspace out to 20NM in range to the ground station, up to 20° in elevation angle, and out to 60° on either side of the runway centerline. Given such information, appropriate data processing, and the application of modern control techniques, curved and segmented approach paths can be defined and flown. Curved and segmented approaches are very different from the current ILS approach. An ILS approach requires the aircraft to track only on the extended runway centerline and on one glide path through the terminal area to landing. However, an MLS curved and segmented approach contains a number of different courses and glide paths, all of which interconnect. ILS avionics and data processing, however, cannot generate usable course and/or glide slope information through an MLS approach.

A recent aircraft simulation study, "MLS Utilization with Conventional Avionics," examined how employing typical ILS data processing and display systems affected pilot performance on MLS approaches. The study confirmed that the systems were inadequate on crossleg segments due to a lack of course guidance. On all profiles, excessive course tracking errors developed on the unguided segments. Pilots found that the navigation problems they had encoutered on the unguided segments also adversely affected their final approach performances. A major conclusion from the study was that course and glide slope guidance should be presented throughout the approach to achieve acceptable levels of performance (ASD TR-76-7).

The study described in this report examines pilot performance using a newly designed Digital Flight Director System (DFDS) which was installed in a T-40 simulator. The DFDS uses MLS azimuth, range, and elevation information to compute course and glide path guidance throughout MLS approaches. DFDS operation requires the pilot to define and input the desired approach path as a sequence of waypoints defined in terms of MLS azimuth, range, and elevation. The DFDS computes a path in space between each succeeding pair of waypoints in the sequence. During the approach, the DFDS continually calculates the distance between the aircraft and the computed approach path and presents appropriate course and glide path guidance to the pilot.

The pilot can program the DFDS in flight, which allows him to define each approach individually. Thus, an air traffic controller could allot a different approach profile to each aircraft under his control. Theoretically, by the use of divergent and separate approach profiles the controller could safely increase air traffic density in the terminal area, which would use airspace and runways more efficiently. Further, properly developed approach profiles could avoid population centers and create effective noise abatement procedures. The high energy MLS signal is virtually distortion free and offers better guidance close to touchdown (TD) for Category II and III approaches. The above capabilities make MLS utilization attractive.

However, the operational flexibility of the MLS can cause some problems. To safely fly MLS approaches, especially in the crowded terminal area airspace, requires that each aircraft be in its designated airspace at all times. Safe MLS approach navigation is dependent not only upon fault-free instrument operation and accurate pilot tracking, but also upon correct approach path definition. The inflight pilot programming capability permits input errors which could define unintended and unsafe nominal approach path. For example, a

pilot could intend to fly an approach intercepting the final approach course 3NM from TD, but actually program an approach with a 1.5NM intercept distance. The pilot, when flying the approach, could only detect such an error using his conventional displays, which were designed for the geometrically much simpler ILS approach. If the pilot failed to detect the error, in all likelihood he would fly out of his designated airspace and into a potentially dangerous situation.

This study had two major objectives. The study was designed to evaluate how well a pilot could determine if he were flying the intended approach path and to examine how profile design factors affected tracking performance.

SECTION II

STUDY PROCEDURE

1. APPARATUS

The experiment was conducted in the Crew Station Design Facility (CSDF), which has the capability to dynamically simulate a complete flight regime under a variety of controlled conditions. The experimental apparatus was the T-40 simulator, which simulates flight in a light two-engine jet aircraft. The T-40 crew station shell was mounted on a motion platform with three degrees of freedom: pitch, 15 degrees down and 25 degrees up; roll, 9 degrees depending on pitch angle; and $\pm$ 12 inches of vertical displacement. The Mark I digital computer controlled all the simulator's functions. With the magnetic tape unit, data on 20 separate parameters were recorded at intervals of 0.2 seconds. The parameters for this study are in Appendix A. The visual simulation equipment was not used.

The T-40 crew station was configured as a T-39 test aircraft with T-39 aerodynamics and instruments (Figure 1). The system contained an Attitude Director Indicator (ADI), powered by the newly designed Digital Flight Director System, with the pitch and bank steering bars operating as processed (command) information. A glide slope indicator (GS), located on the left side of the ADI, displayed unprocessed (raw) glide slope deviation via a pointer moving over a vertical scale. A rate-of-turn indicator and an inclinometer were located on the bottom of the ADI. Located below the ADI was the Horizontal Situation Indicator (HSI), which contained the Course Deviation Indicator (CDI). The CDI presented unprocessed (raw) localizer information. A heading set knob and a course set knob rotated a small white heading indicator about the compass. The course set

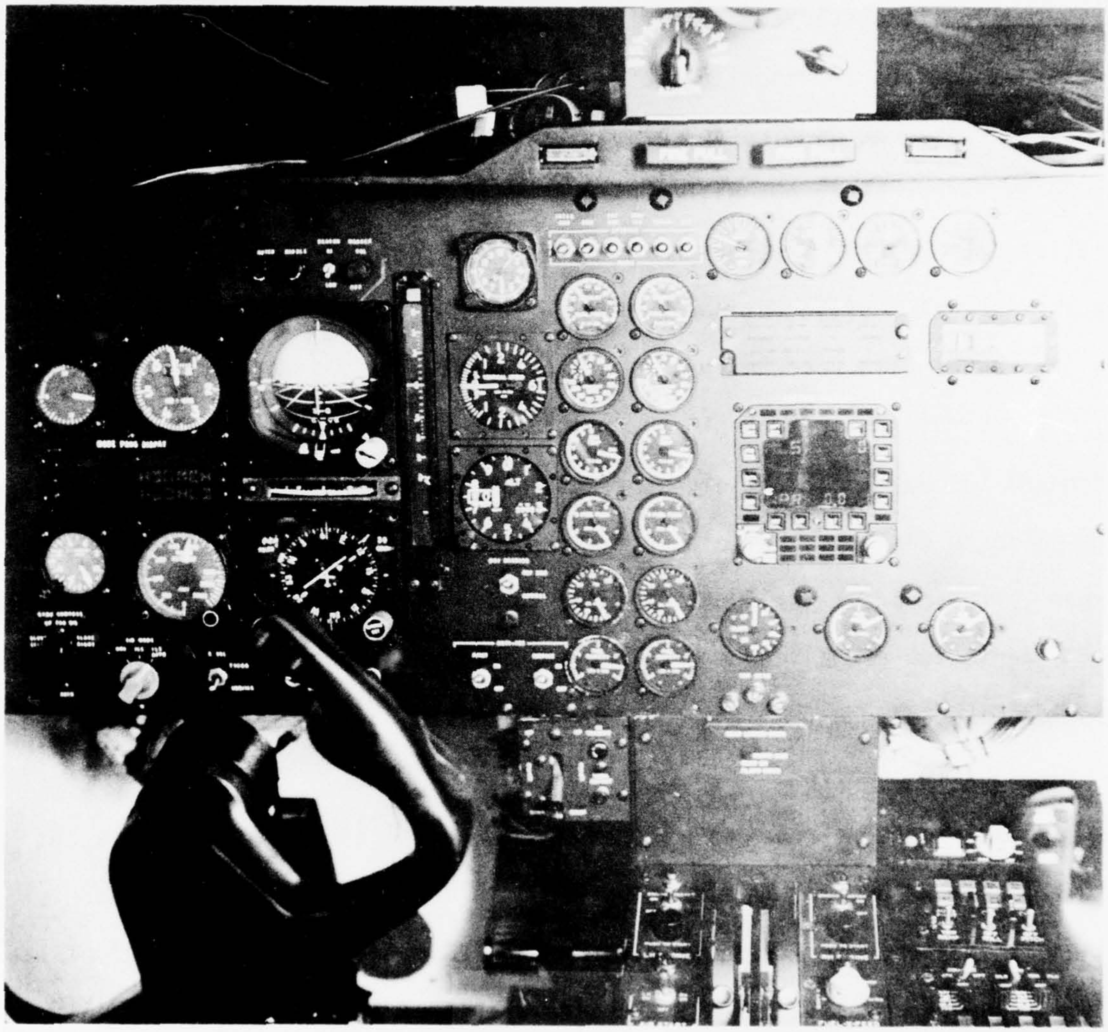


Figure 1

Crew Station Configuration

knob operated the digital course indicator in the upper right portion of the HSI and could reposition the CDI when the aircraft was receiving course information. The distance from the MLS azimuth transmitter was given by the three-digit DME readout in the upper left corner.

Mounted between the ADI and the HSI was the Azimuth Angle Indicator (AAI) (Figure 2). It displayed aircraft position (pointer) in relation to a scale marked in degrees representing MLS radials. The 0° mark referred to the extended runway centerline and was located at the center of the scale. The scale extended out to 60° either side of the 0° mark in a nonlinear fashion, with the larger units nearer the 0° mark. The indication displayed in Figure 2 marks aircraft position at some point on the 20° left radial, which corresponds to the radial used for the initial leg of profiles, 1, 2, and 4.

The simulator instrument system included the DFDS, which replaced the standard ILS analog flight director system. The DFDS did not physically change the guidance displays, but did change their information sources. In the DFDS range to the transmitter (DME), bearing to the station, HSI course readout, and CDI orientation are all dependent upon and updated by the DFDS. However, the most dramatic change from the ILS concerns the relationship of processed and unprocessed information.

An ILS airborne receiver is designed to detect aircraft position about the ILS beam which, due to the geometric simplicity of the ILS approach, is actually course and glide slope error. The ILS receiver sends its outputs to the CDI and G/S indicator where they are displayed as course error and glide slope error, respectively. These same ILS receiver outputs are also sent to the analog flight director system, which further processes the information and presents it as command guidance on the pitch and bank steering bars. In the

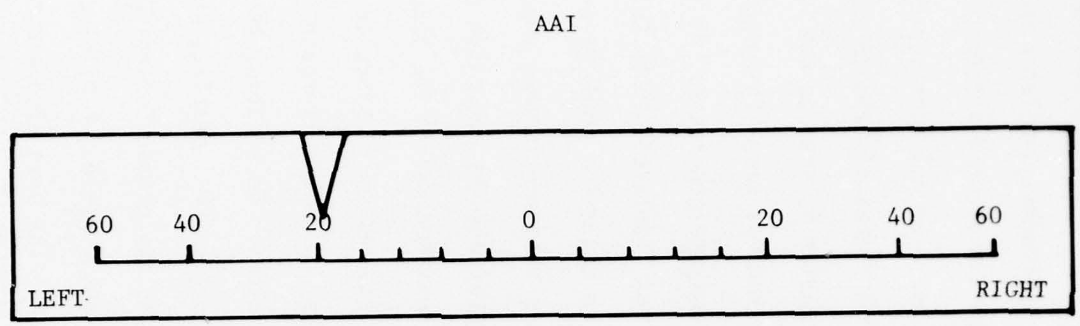


Figure 2.- Azimuth Angle Indicator

ILS system, the unprocessed information displays give the pilot a form of position information which can be used to determine aircraft location in the terminal area.

The DFDS is much different. The broad MLS coverage, more complex MLS approach design, and the variety of unique MLS approaches available have necessitated that the DFDS compute processed and unprocessed information and send such information to the appropriate displays. The MLS receiver receives aircraft position information, which is defined in terms of azimuth angle, elevation angle, and range. The position information is sent to the DFDS where the distance between the aircraft and the nominal track is computed. On this basis, course and glide slope error values are generated. At this point, course error and glide slope error are sent to and displayed by the CDI and G/S indicator, respectively. However, the course and glide slope error values are also sent to other portions of the DFDS where they are further processed to generate command guidance signals which are presented by the pitch and bank steering bars. Both processed and unprocessed guidance, as in the ILS, refer to aircraft position relative to the nominal track. However, since in the MLS environment a pilot could be flying on one of many different approach paths, he must crosscheck his absolute location at all times. To do this, he must use and integrate other sources of information such as DME, bearing, and altitude.

The pilot's access to the DFDS is through the Navigation Control Display Unit (NCDU) located in the center of the instrument console. A pilot could use it to program information during the approach. The unit also had many other functions, which were not needed during testing.

A mode progress display, located left of the ADI, was a three-window display used to aid the pilot during capture and throughout the approach. Glide slope (G/S) and localizer (LOC) capture were indicated by the mode progress display. When capture occurred, the appropriate display changed from green to orange. The mode progress display also notified the pilot when the final approach leg was encountered by displaying an orange "CAT II" symbol.

2. SUBJECTS

Fourteen USAF pilots from the 4950th Test Wing participated as subject pilots. The group averaged 29 years of age, 6.4 years service time, and 1641 hours of flight time.

3. EXPERIMENTAL DESIGN

The experiment was a completely randomized block design which employed two factors. The first factor was the type of unintended flight path. The second factor, profile design, dealt with how various aspects of profile design affected tracking performance.

During testing, every subject flew a random sequence of 40 test approaches. The sequence differed for each subject, but every subject flew each of the eight profiles (Figure 3) five times (see Appendix C for details). Superimposed over every 40 trial sequence was a random sequence of ten discrepant (see Subsection III-4 Discrepancy Design) and 30 nondiscrepant conditions. Each such sequence was varied from subject to subject, but always included two instances of discrepancies types I, IIA, and IIB and one occurrence of types IIIAX, IIIAY, IIIBX, and IIIBY.

During a discrepant condition the experimenter, unbeknown to the subject, altered the DFDS software to introduce one of the seven navigation discrepancies. On nondiscrepant trials, the pilot flew the intended profile.

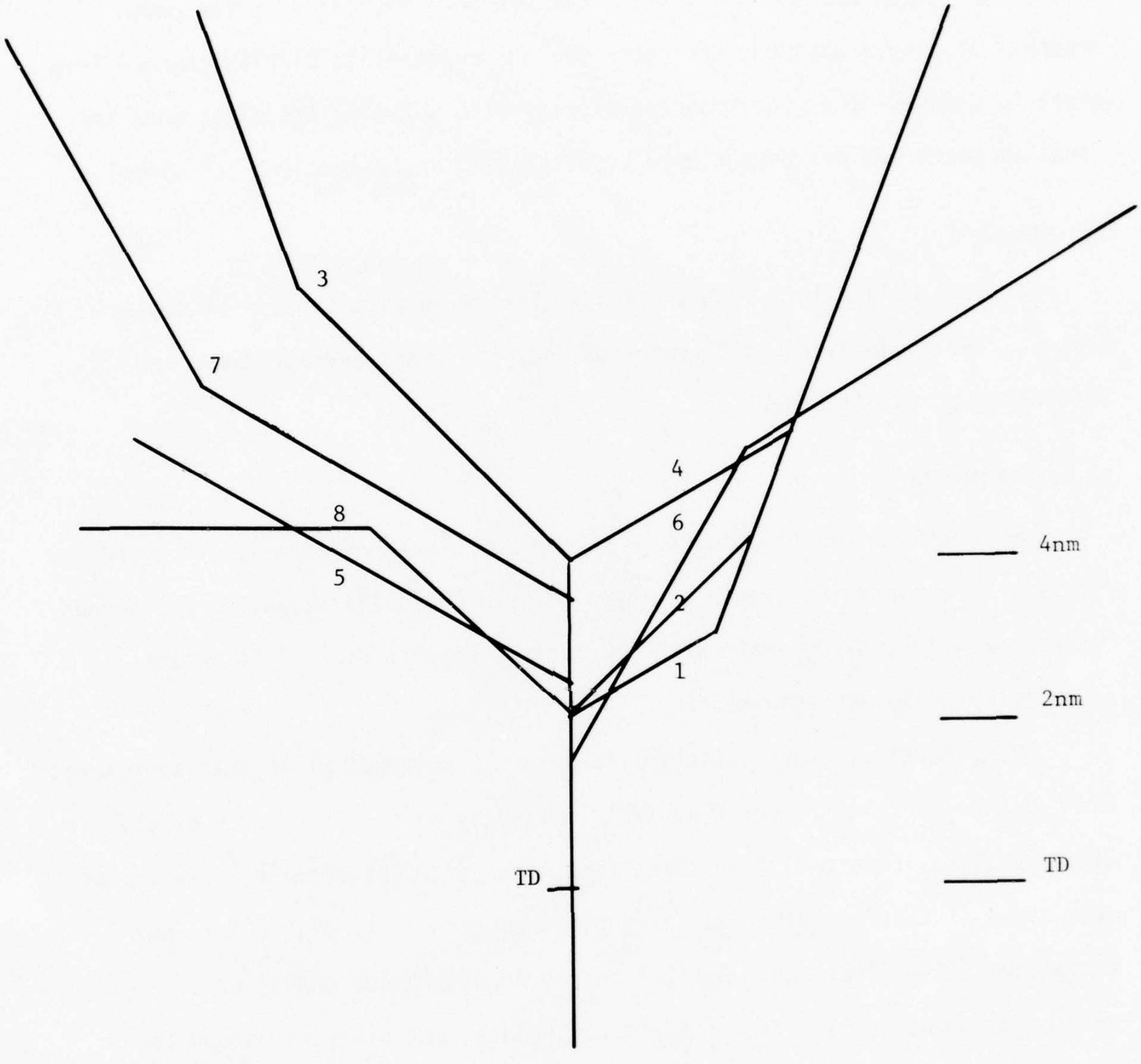


Figure 3
Profiles*

*See Appendix C for more detail

4. DISCREPANCY DESIGN

Presented in Figures 4, 5, and 6 are the navigation discrepancies used in this experiment. Listed in Table 1 are brief descriptions of each discrepancy and a short explanation of how each one could be detected. Additional information on the pilot procedures required to detect each discrepancy are given in Appendix B.

The discrepancies were designed to highlight navigation problems that could create unsafe conditions, especially in Category III--weather. The nature of the present DFDS design affected discrepancy implementation. Some could be implemented by simulating one simple pilot programming error while others required a more complex simulation. In either case, the effort was to create problematic navigation conditions and avoid devising discrepancies unique to the present DFDS design.

5. PROCEDURE

The experimenter briefed every subject on the purpose of the experiment and about the MLS approaches and the DFDS. He also described in general terms what a navigation discrepancy was and cited each type of guidance and position information and traced its source. Although the pilots were not given exact descriptions of the discrepancies they were to receive, they were told to monitor course, heading, turn point range, altitude, and rate descent and given detection criteria. Afterward, the experimenter escorted the subjects to the simulator and showed them how to operate the DFDS.

After the briefing and DFDS demonstration, each subject flew two sets of five practice approaches in which all eight profiles were flown once, except for profiles 5 and 6, which were flown twice. No discrepancies were introduced

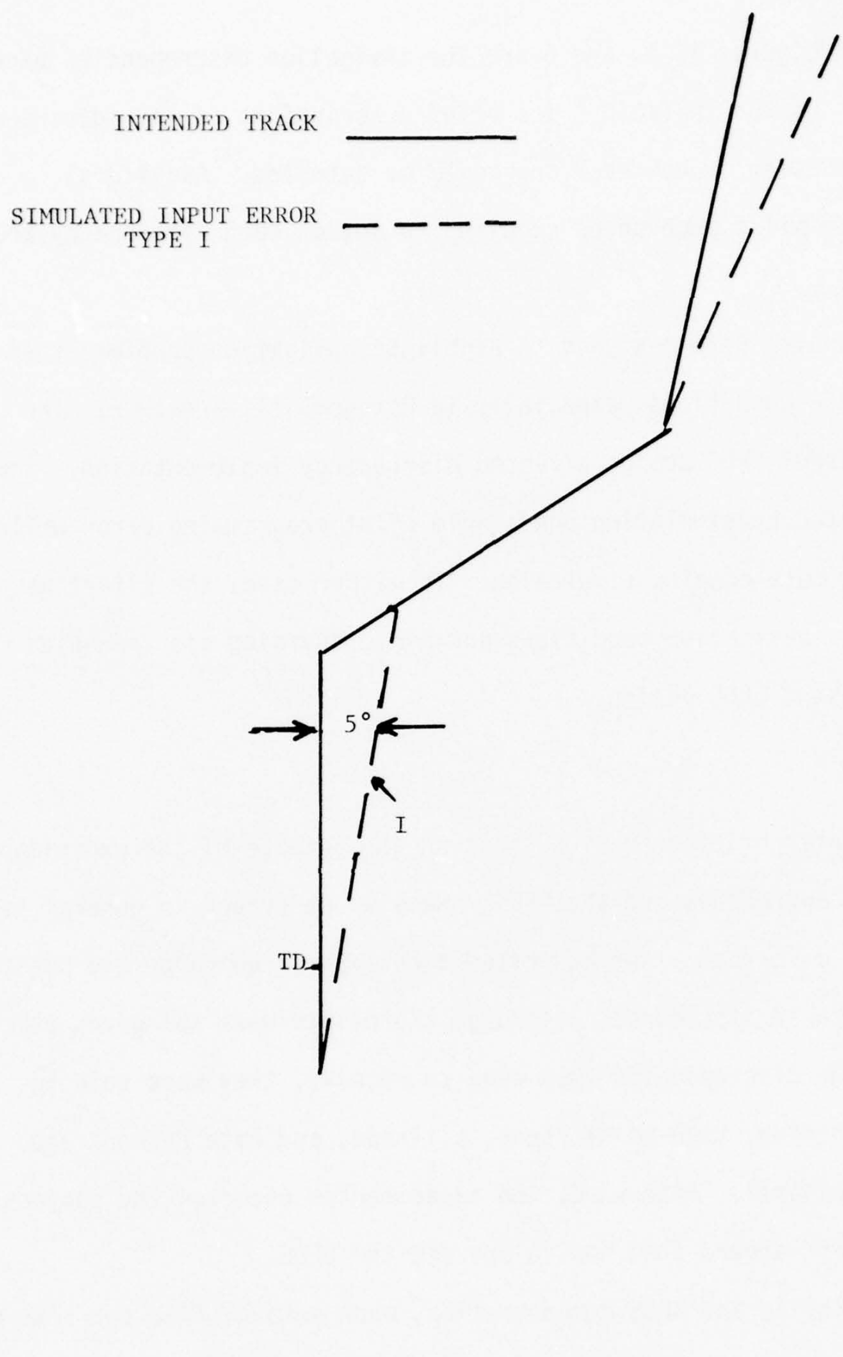


Figure 4
FINAL APPROACH
COURSE OFFSET

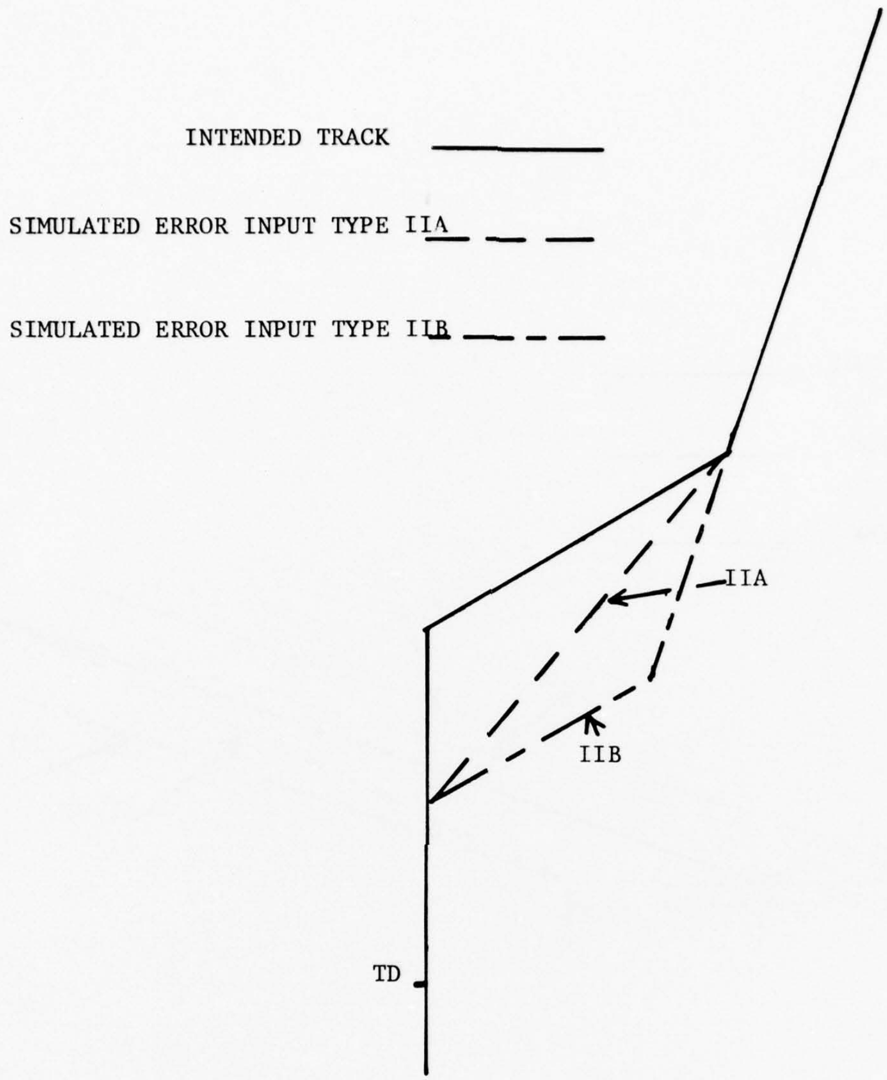


Figure 5
CROSSLEG OFFSETS

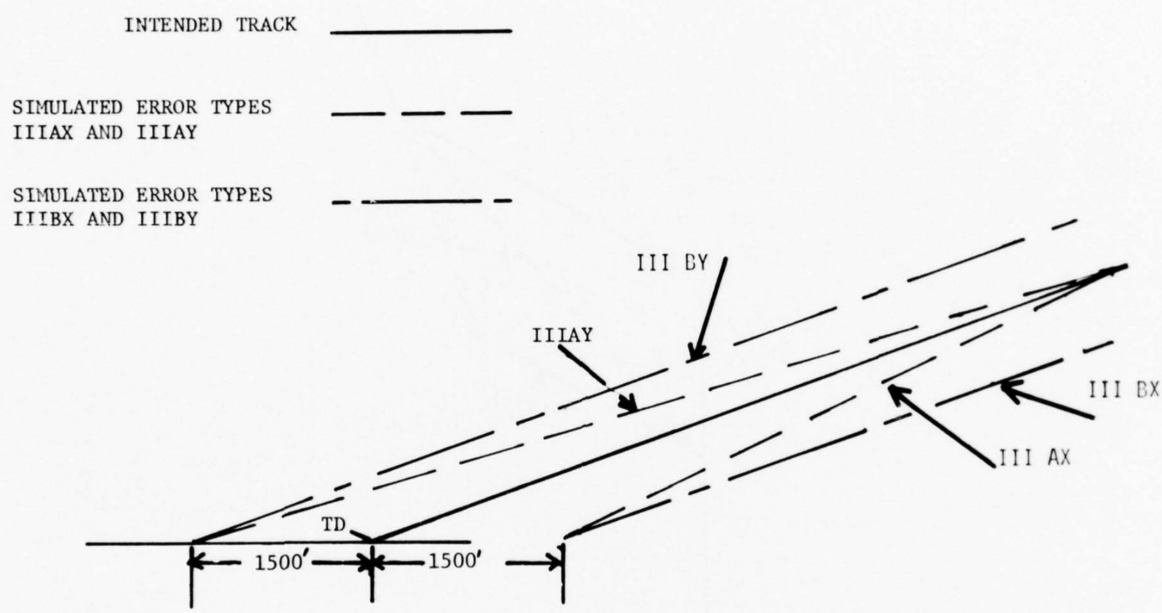


Figure 6
FINAL APPROACH
GLIDE PATH OFFSETS

TABLE 1

DISCREPANCY DESIGN AND DETECTION*

TYPE	DESCRIPTION	DETECTION METHOD
I	Non-parallel offset of final approach course	Compare HSI course readout or AAI indication with that expected.
IIA	Non-parallel offset of crossleg course	Compare HSI course readout or heading with that expected.
IIB	Late crossleg intercept turn	Note DME range at the beginning of the crossleg intercept turn and compare with that expected.
IIIA (X or Y)	Non-parallel offset of final approach glide path	Compare expected with the actual rate of descent.
IIIB (X or Y)	Parallel offset of final approach glide path	Compare expected altitude with computed path altitude at the beginning of the final approach intercept turn.

*See Appendix B for more detail.

during practice. During testing, every subject flew two, five approach sets daily and rested between each set. After a set, each pilot answered the MLS Post Mission Questionnaire (see Appendix D). After completing the 40 test approaches, each answered the MLS end of Study Questionnaire (see Appendix D).

To start an approach, the pilot input the intended waypoint sequence into the DFDS while the experimenter set the aircraft simulator at the proper altitude, location, heading, and airspeed. Upon the pilot's request, the experimenter transferred control of the aircraft simulator from the computer to the pilot. After transfer of control, the pilot could use only the CDI and GS guidance displays, since the DFDS did not present command guidance until the pilot intercepted the nominal path. Once intercepted, the steering bars displayed command guidance and did so throughout the approach.

6. TRACKING PERFORMANCE SCORING SYSTEM

Each MLS pattern was divided into five zones for scoring. Zone 5, the final approach, terminated at 200 ft above field elevation. Zone 4, the turn onto the final approach, connected zone 5 with zone 3, the crossleg. Zone 2, a turn, connected zone 3 with zone 1, an initial portion of each approach profile.

Within each leg, four parameters were tabulated to describe the aircraft's performance. Airspeed error score (A/S), lateral tracking error score (Y), vertical tracking error score (Z), and a combination score (YZ) consisting of both lateral and vertical tracking error, were collected. Each Y and Z value represents the actual distance in feet of the aircraft from the nominal track, laterally and vertically. Each YZ value is the distance in feet between the aircraft and the desired track and was calculated using the Y and Z value at

each interaction and the Pythagorean Theorem. Each airspeed value was the difference between the aircraft indicated airspeed and 140 kts at each iteration. Each A/S, Y, Z and YZ value was computed every 0.2 second, an absolute value determined, summed with the other values of that parameter for that leg, and divided by the number of iterations during that leg to produce a score for that parameter on that leg. Each parameter value and score (absolute average error term) was calculated, depending upon leg number and pattern number.

Essentially, the scoring system tabulated a set of absolute average error (AAE) terms which described how closely the pilot flew the aircraft to the nominal track at the desired airspeed for each leg. Each AAE term reflects not only consistently poor performance, but also tracking performance which oscillates about the nominal track. Differences among AAE terms for a particular parameter accurately reflect differences in tracking performance. The AAE terms, by their nature, are normalized for time and distance and therefore permit comparisons across pattern types (see ASD TR-76-7 for more detail).

SECTION III

RESULTS

The data were divided into two groups. On trials which did not involve a waypoint discrepancy, tracking performance scores were obtained. On approaches involving a waypoint discrepancy, the data of interest were the pilot's abilities to detect the discrepancies.

The tracking performance scores for the crossleg are graphically depicted in Figure 7. The crossleg is the straight leg segment immediately preceding the final approach. For each profile, the mean lateral error and the mean vertical error scores are displayed, which make up, as discussed in the Scoring System section, the mean combination score. Figure 7 shows that on each profile the mean lateral error score greatly exceeded the mean vertical error score. In fact, the mean lateral error score was almost as large as the mean combination score, which left the mean vertical error scores relatively insignificant. This finding demonstrates that controlling lateral error was the predominant problem on the crossleg.

An analysis of variance was performed on the crossleg mean combination scores across profiles. The results (Table 2) show that the type of profile flown significantly affected performance ($p \leq .01$). To evaluate which differences among the profile mean scores were significant, a Newman-Kuels test was performed. The Newman-Keuls test, designed to perform pair-wise comparisons, revealed that the exceptionally high mean combination scores for profiles 2 and 4 differed significantly ($p \leq .01$) from the other profiles. The comparisons also demonstrated that the mean combination scores for profiles 2 and 4 demonstrated the relative performance difficulty of these profiles.

Final approach performance, graphically pictured in Figure 8, depicts tracking performance across profiles. On each profile the mean combination

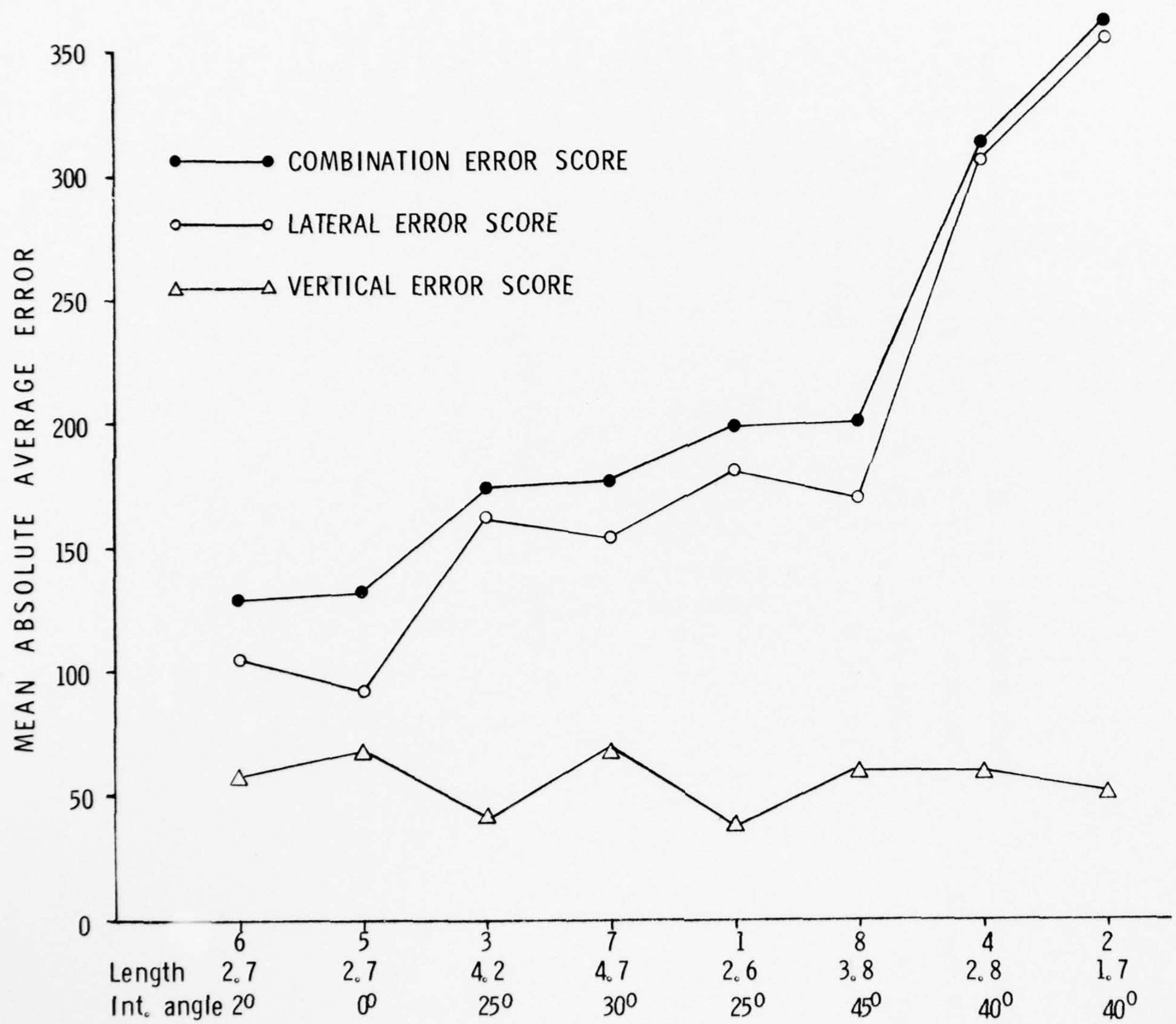


Figure 7

CROSSLEG PERFORMANCE

TABLE 2

ANALYSIS OF VARIANCE SUMMARY TABLE

CROSSLEG TRACKING PERFORMANCES

Source	Sum of Squares	df	Mean Square	Ratio
Profile Type (A)	685,633.3	7	97,947.6	** 11.95
Subject (S)	5,338,466.5	13	410,651.3	
Error Term (AS)	745,721.7	91	8,194.7	

** 11.95; p .01 F (7,91)

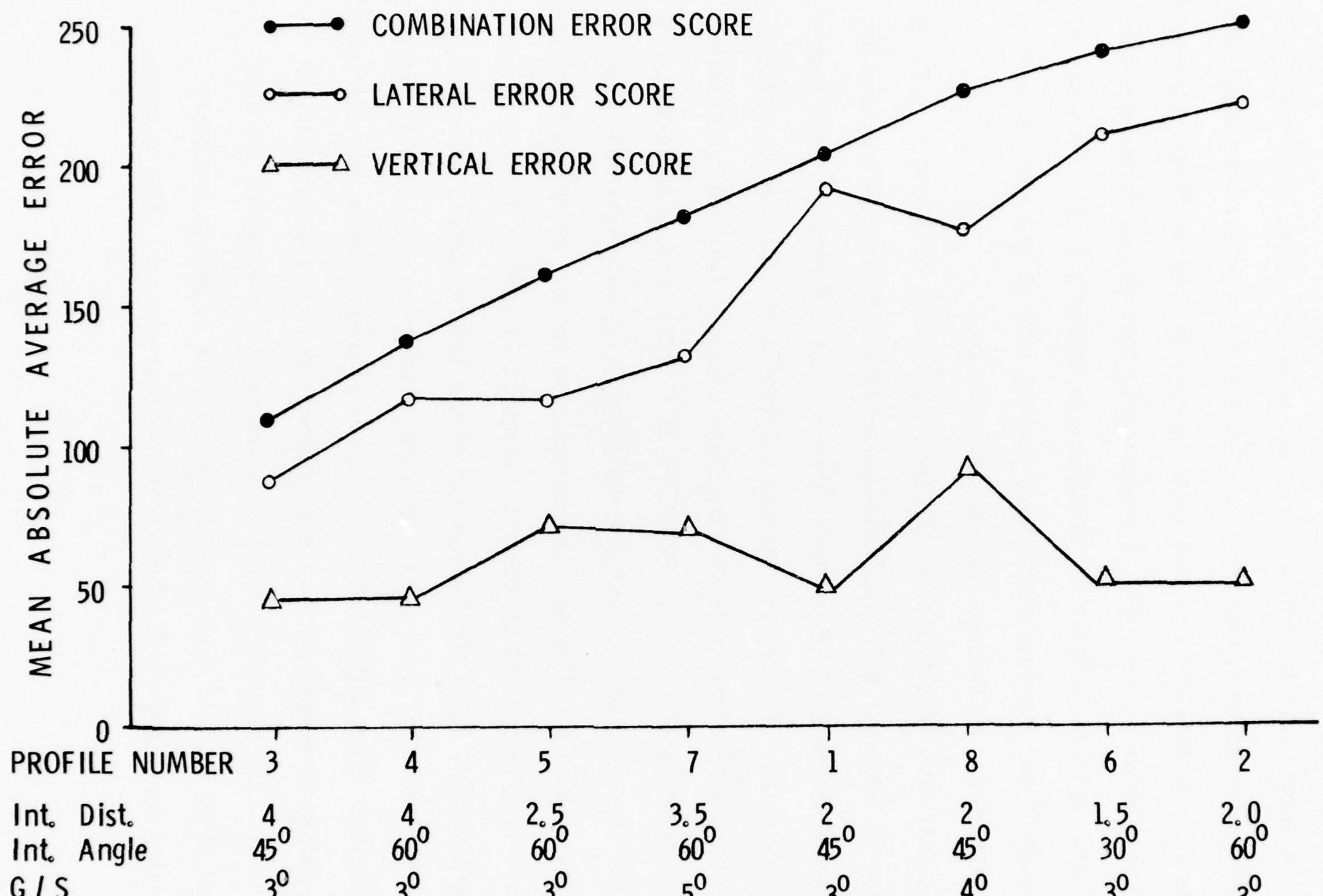


Figure 8

FINAL APPROACH PERFORMANCE

error score is separated into its mean lateral error and mean vertical error scores. A second analysis of variance was performed on the final approach mean combination error scores across profiles and the results are displayed in Table 3. The analysis revealed that the type of profile flown significantly affected performance ($p \leq .01$). A Newman-Keuls test was performed and the test results are depicted in Table 4. Contained in Appendix E is a breakdown of crossleg and final approach performance showing lateral and vertical error scores per profile as well as the combination score.

The data from trials with discrepant waypoints is displayed as percent detection in Table 5. A Friedman Two-Way analysis of variance was done on the data and showed that the percent detection was a function of the type of discrepancy given. The analysis showed a marked difference in the percent detection between lateral situation discrepancies (I, IIA, IIB) and vertical situation discrepancies (IIIAX, IIIAY, IIIBX, IIIBY), revealing that lateral types were more detectable. This not to convey that only vertical situation discrepancies were problematic. On average, the lateral situation discrepancies were noted only 78 percent of the time, which still left 22 percent of the errors undetected. With about a quarter of the lateral errors unnoticed, it is difficult to assert that pilots adequately recognized the lateral situation discrepancies. Thus, detection of both types of discrepancies was difficult.

Contained in Appendix F is a data summary from the MLS Post Mission Questionnaire. In essence, those pilots who initially accepted the DFDS continued to do so, and those who first distrusted it maintained their skepticism. Regarding the MLS End of Study Questionnaire, pilot comments

TABLE 3

ANALYSIS OF VARIANCE SUMMARY TABLE

FINAL APPROACH TRACKING PERFORMANCES

Source	Sum of Squares	df	Mean Square	F Ratio
Profile Type (A)	240,014.95	7	34,287.85	**5.88
Subjects (S)	293,012.36	13	22,539.41	
Error Term (A&S)	530,666.78	91	5,831.50	

** 5.88; p .01 F (7,91)

TABLE 4

FINAL APPROACH PERFORMANCES

NEWMAN-KEULS ANALYSIS SUMMARY TABLE

PROFILE		3	4	5	7	1	8	6	2
PROFILE	3		18.5	43.3	63.4	91.4	*108.2	*125.0	*132.8
	4			24.8	44.9	72.9	89.7	*106.5	*114.3
	5				20.1	48.1	64.9	81.7	89.5
	7					28.0	44.8	61.6	69.4
	1						16.8	33.6	41.4
	8							16.8	24.6
	6								7.80
	2								

* p .01

TABLE 5

DISCREPANCY DETECTION

Failure Type	Percent Detection
I	68
IIA	93
IIB	74
IIIA	4
IIIB	0

correlated highly with pilot tracking performance, in that those profiles cited as hard to fly were so. Some criticism of the testing procedure was given. The lack of a more dynamic, complicated approach environment in which other aircraft, air-to-ground communications, and intra-crew coordination are typical, may have caused discrepancy detection percentages to be too high and unrepresentative of an actual situation.

SECTION IV

DISCUSSION

The crossleg performance data displayed in Figure 7 suggests that the degree of heading change required to intercept the crossleg course could have affected crossleg performance. In essence, the greater the course change required, the more the opportunity for error existed. On the profiles flown, the amount of course change required to intercept the crossleg ranged from 0° to 45°. Profiles 2 and 4, those with the highest mean error scores, each required 40° of course change. This was at least 15° greater than that required for all other profiles. except for the 45° course change found on profile 8. However, the mean combination error score for profile 8 was significantly less than that for 2 or 4. An examination of crossleg lengths should clarify the issue. The crossleg lengths of profiles 2, 4, and 8, were 1.7 nm, 2.8nm, and 3.8 nm, respectively, and suggest that the longer crossleg of profile 8 helped reduce its crossleg mean error score.

Two factors seem to be interacting: course change required to intercept the crossleg and crossleg length. On profiles with shorter crosslegs (i.e., less than 3.0 nm), the amount of course change required to adopt the crossleg affected tracking performance. On such segments, significantly higher mean combination scores occurred on segments with high intercept angles. Larger turns were more difficult and such difficulties caused tracking errors that were too great to be quickly corrected on short segments. However, when operating independently, the effects of a large intercept angle (e.g., profile 8) could be dampened by a long crossleg segment and the influence of a short crossleg could be offset by a shallow intercept angle (e.g., profile 1).

The differences among scores for final approach performances across profiles shown in Figure 8 can be largely explained by examining the various levels of intercept distance. For example, the intercept distance of profile 3 was 4 nm, while those of profiles 2, 6, and 8 were about 2 nm. The arrangement of mean combination scores was the same as the above arrangement of intercept distances, with the score for profile 3 being significantly less than those of the other profiles. Other performance differences were similar and indicate that longer final approaches fostered superior tracking performance. On the longer final approaches, pilots spent proportionately less of the total tracking time available for that segment recovering from the intercept turn and were able to devote more time to precisely tracking the nominal path.

The effect of intercept angle can be examined by comparing the mean combination error scores for profiles with equal intercept distances but unequal intercept angles. Comparing the mean error score of profile 3 to that of profile 4 and the mean score of profile 2 to that of profile 1 shows no significant differences based on the Newman-Keuls test. Varying glide slope angle also did not significantly affect the mean combination scores.

As shown in Table 5 a type IIA discrepancy, a nonparallel displacement of the crossleg, had the best detection rate. The HSI clearly displayed the heading error and the course error and continued to do so as long as the aircraft remained on the crossleg. The presence of such obvious and long duration cues enabled the pilots to consistently detect a type IIA.

However, other discrepancies did not present such lengthy detection cues. A type IIB could be detected only during the turn onto or off of the crossleg. During such periods pilots needed to reference the DME display on the NCDU to detect the error. The type IIB detection rate would probably have been

higher had pilots consistently referenced the NCDU display during turns, but they occasionally failed to do this due to pressure to satisfy the bank steering bar.

Discrepancy types IIIBX and IIIBY also did not present long duration cues and could be discovered only during the turn to final approach. The nature of the discrepancy and the display design forced pilots to use a complex detection procedure. The aircraft's constant descent caused the glide path error values on the NCDU and the barometric altimeter readings to constantly change. Further, the barometric altimeter had 50 feet interval markings and an error tolerance of about ± 50 feet and hampered the pilots from obtaining a useful reading. In essence, pilots found it quite difficult to check the NCDU and the altimeter quickly and accurately and, thus, were at points other than the checkpoint when obtaining glide path error and altitude values. Finally, during all of this, the pilot was pressured to satisfy the bank steering bar, which had been leading him through a turn onto the final approach course. The discrepancy detection procedure was quite difficult to handle even given ample time. Shortness of time forced the pilot to either perform the computations hastily and inaccurately or to ignore them. Thus, the discrepancy went undetected.

A type IIIAX or IIIAY was as difficult to detect as either type IIIB. When tracking a glide path, the constant throttle adjustments, pitch changes, and rolling moments caused the aircraft's rate of descent to be constantly changing. The rate of descent oscillations occurred always, regardless of the beam type of glide slope angle. The changing rate of descent values

were reflected by the wide range of VVI pointer oscillations, which made it difficult for a pilot to accurately compute the aircraft's average rate of descent. Thus, a pilot could have postulated only approximate values for the aircraft's rate of descent (e.g., about 700-800 FPM), which made it extremely difficult for him to make the discrimination that the aircraft's true rate of descent differed by 100 FPM from that expected. Thus, pilots essentially could not detect the potentially fatal glide path angle discrepancies included in this study.

A type I discrepancy, a nonparallel displacement of the final approach course, presented long duration cues as did a type IIA. The 25 percent difference between their detection rates, although not statistically significant, may be significant from a safety of flight perspective. A 68 percent detection (type I) would be much less preferable than 93 percent (type IIA) and would warrant improvement, especially since the 68 percent rate was for a final approach discrepancy. Further, even a small navigation error can seriously affect flight safety on the final approach segment, whereas a comparable error on the crossleg would be uninfluencial. Thus, a pilot's discrepancy detection should become more acute on final approach, but the data suggests that this may not be true.

The pilot's tasks on the final approach were similar to his tasks on the crossleg, in that he was to keep the aircraft under control at all times and within the designated airspace. Traveling from initial segments to and over the crossleg took the pilot and his aircraft through an air corridor of relatively large and unchanging dimensions. Once on final approach, however, each moment of flight shrank the size of the designated airspace and caused

the pilot to devote more and more effort to keep the aircraft within said airspace. As the pilot devoted more attention to satisfying the command steering bars, he could give less to crosscheck items like the HSI course readout and, in this manner, overlooked the type I discrepancy.

In summary, pilots can consistently detect a discrepancy (i.e., type IIA) if the needed information is presented for a long period and is easily perceived and integrated into the piloting task. However, detection becomes sporadic when the relevant information is difficult to use, pilot workload is high, and/or the cues are of a short duration. The data suggest that pilots need position information that is easily perceived and integrated into the piloting task. This could reduce pilot workload by simplifying discrepancy detection procedures and also enable pilots to improve their detection of discrepancies with short duration cues. However, high pilot workload can cause even obvious cues to be ignored, which suggests that providing better position information will not completely solve the problem.

Another approach to MLS flight safety might be to use the aircraft and ground station to reduce the probability of a discrepancy. Ground station or DFDS alterations could insure that only an accurate and safe final approach course and glide slope be programmable. In effect, such a change would establish the final approach coordinates in the DFDS and would thereby relieve the pilot of programming the final approach. The role of the ground station and DFDS could be expanded so that the pilot or the air traffic controller could select a certain approach profile and input all the profile coordinates in one step. The pilot then would be unable to make errors in waypoint definition and selection and he still could verify the accuracy of the coordinates prior to flying the approach. However, to gain user acceptance and to facilitate discrepancy detection when the above cited precautions fail, the pilot's ability to monitor aircraft position during an approach must still be improved.

SECTION V

CONCLUSIONS

Intercept angle and crossleg length interacted to produce poorer crossleg performance on profiles with short crosslegs and high intercept angles.

Leg length was the influential factor in final approach performance. Longer segments allowed pilots to more effectively recover from tracking errors that occurred during hte previous turn.

Discrepancy detection was problematic. Detection difficulties point to a need to provide pilots with better, not necessarily more, position information. Further, a need may exist to limit the flexibility of the MLS. The data indicated that MLS flexibility, while being one of its more potent strengths, may also turn into one of its most serious weaknesses.

APPENDIX A

PARAMETERS RECORDED EVERY 0.2 SECONDS

Patern Number

Mission Number

Subject Number

File Count

Geographic Altitude

Latitude

Longitude

Position on A-axis (Feet)

Position on B-axis (Feet)

Lateral error from nominal track (Feet)

Vertical error from nominal track (Feet)

N updates per leg

Indicated Airspeed (IAS) (KTS)

IAS - 140 KTS

Pitch Angle

Roll Angle

Sin of Aircraft Heading

Cosin of Aircraft Heading

Throttle position

Rate of Climb

APPENDIX B

DETECTION PROCEDURES

The design of a type I (figure 4) was affected by the DFDS design, such that both the initial segment and the final approach segment had to be displaced. However, detection of the inaccurate final approach course was the real item of interest. A pilot could detect the inaccurate final approach course by either referencing the course readout on the HSI, which was automatically updated by the DFDS, or by looking at the AAI. The HSI course readout would have read 176 instead of 171 and the AAI would have its pointer to the left of the 0° index, which represented the final approach course, instead of centered over the 0° index. In either case, pilots were told to cite any course error in excess of $\pm$ 2° as a discrepancy.

A pilot could detect a type IIA (Figure 5) by referencing the course readout on the HSI. Again any error in excess of $\pm$ 2° was to be considered a discrepancy. Since no winds were involved, aircraft heading should coincide with the intended course and allowed pilots to use the heading indicator to detect a type IIA.

To detect a type IIB (Figure 5) required the pilot to cross check his DME (to the station) at the onset of the turn onto the crossleg. If this was not done, the discrepancy could still be discovered if the pilot checked the DME while making the turn onto the final approach course. Discrepancies involved errors which were usually about .7nm and were best detected using the DME readout on the NCDU data display, which operated during every approach and pilots were told to reference it.

To discover either a type IIIAX or IIIAY (Figure 6) the pilot needed to estimate the aircraft's average rate of descent by observing Vertical Velocity

Indicator (VVI) values and then had to compare his rate of descent estimate with that expected for that glide slope value. A difference in excess of about 100 FPM was to be cited as a discrepancy.

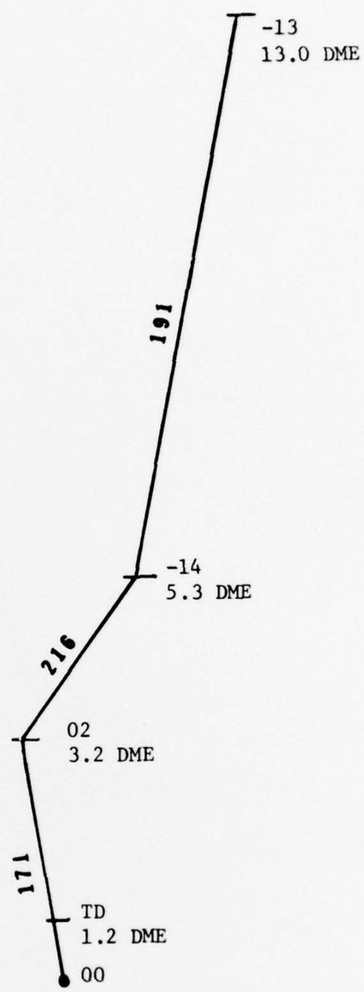
Either type IIIB (Figure 6) involved offsetting the altitude of the computed track at the onset of the turn onto final about 100 feet low IIIBX) or 100 feet high (IIIBY). The discrepancy detection procedure required the pilot to reference his barometric altimeter first as the bank steering bar displaced laterally, initiating the turn onto final. Timing was important. After checking aircraft barometric altitude, the pilot had to immediately note the glide slope error on the NCDU. If he was high he had to subtract the glide slope error from the barometric altitude value and, if low, he had to add. This computational procedure gave the pilot the altitude of the computed path at the checkpoint, a difference between the computed path altitude and that of the nominal one in excess of 75 feet constituted a discrepancy.

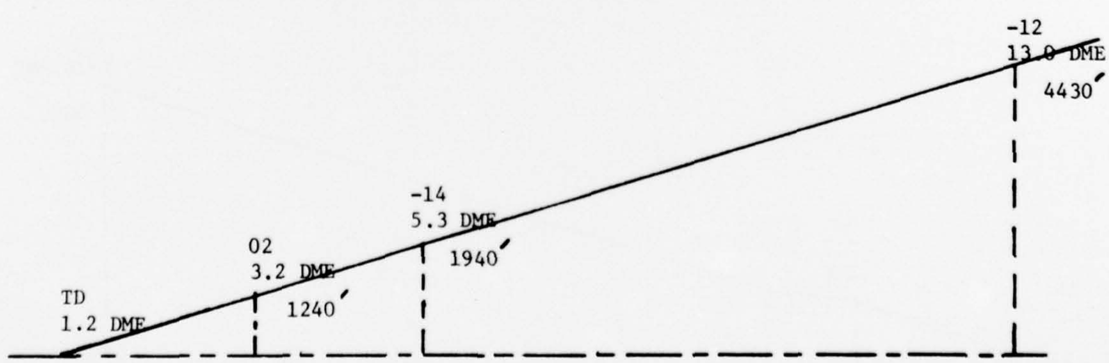
APPENDIX C

PROFILE DESIGN

PROFILE 1

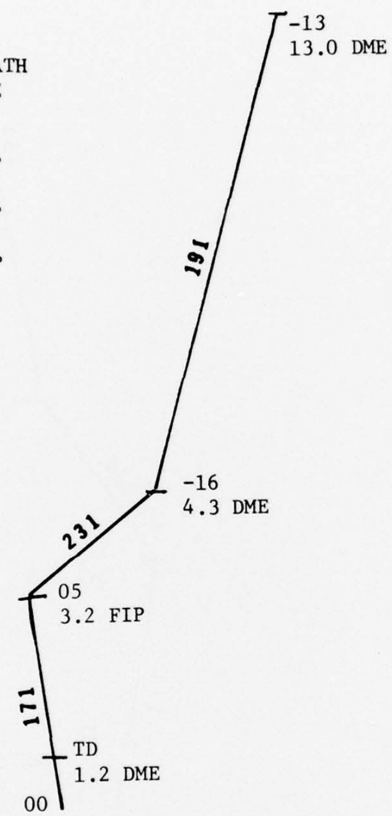
WAYPOINT SEQUENCE	GLIDE PATH ANGLE
-13	3.2°
-14	2.8°
02	3.0°
00	

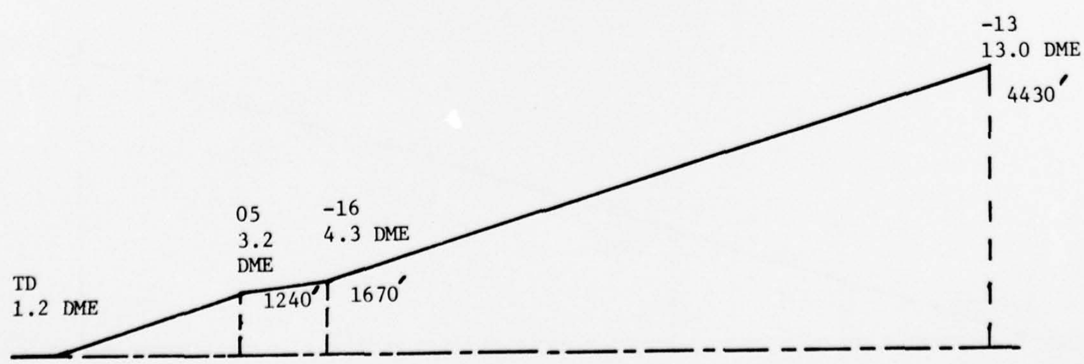




PROFILE 2

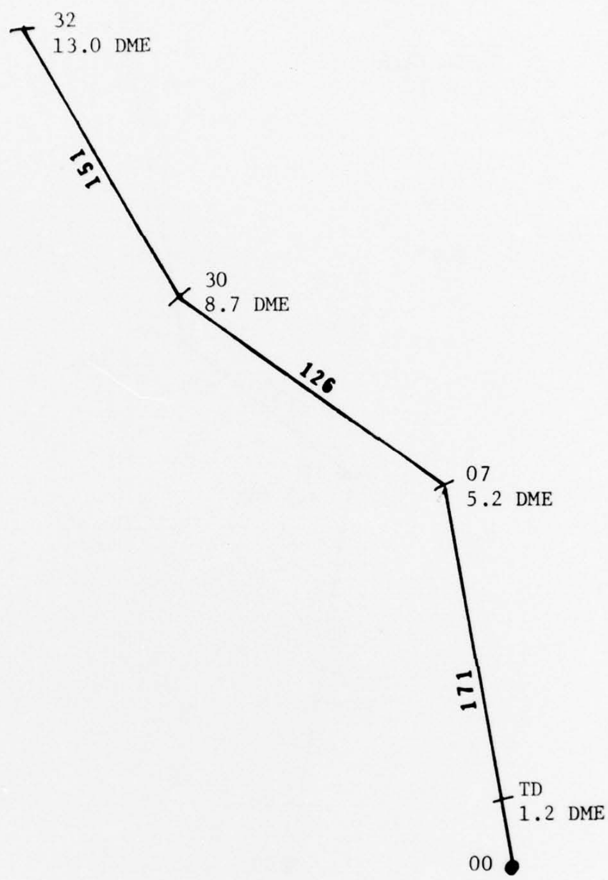
WAYPOINT SEQUENCE	GLIDE PATH ANGLE
-13	
	3.2°
-16	
	2.5°
05	
	3.0°
00	

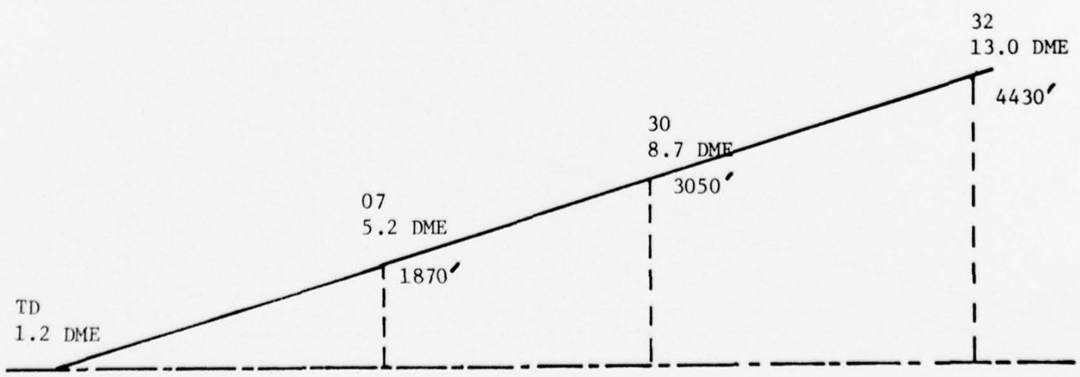




PROFILE 3

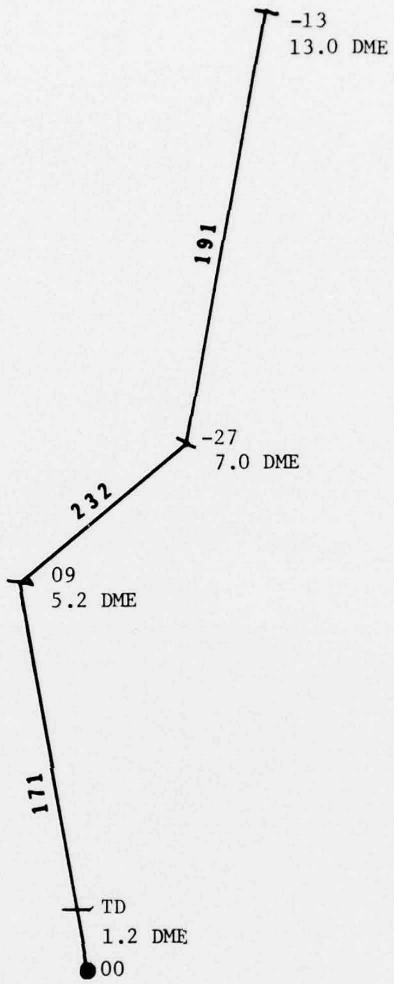
WAYPOINT SEQUENCE	GLIDE PATH ANGLE
32	
	3.2°
30	
	2.8°
07	
	3.0°
00	

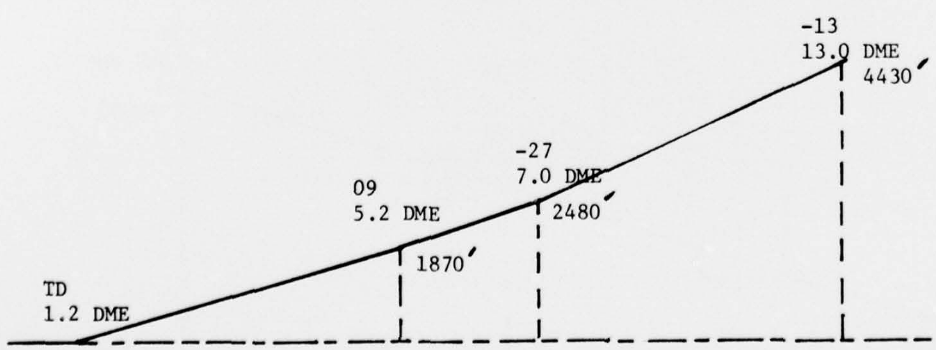




PROFILE 4

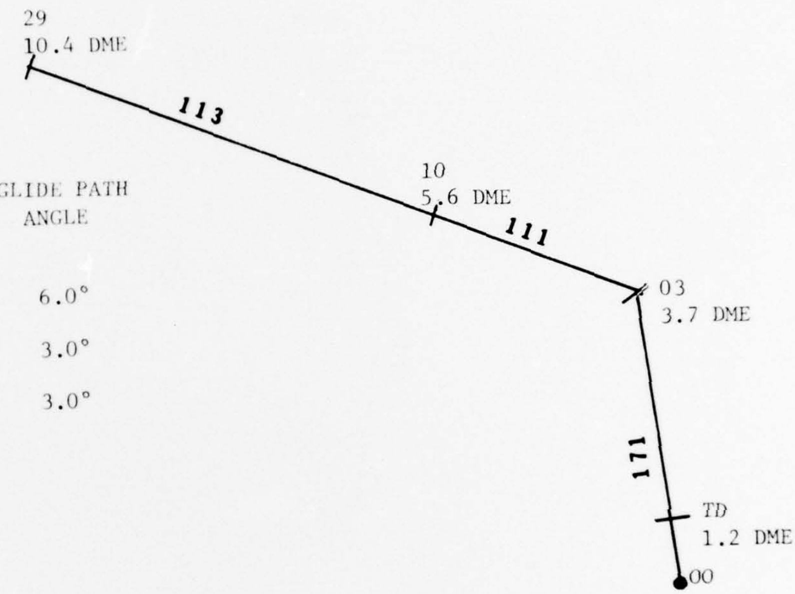
WAYPOINT SEQUENCE	GLIDE PATH ANGLE
-13	
	3.3°
-27	
	2.3°
09	
	2.9°
00	

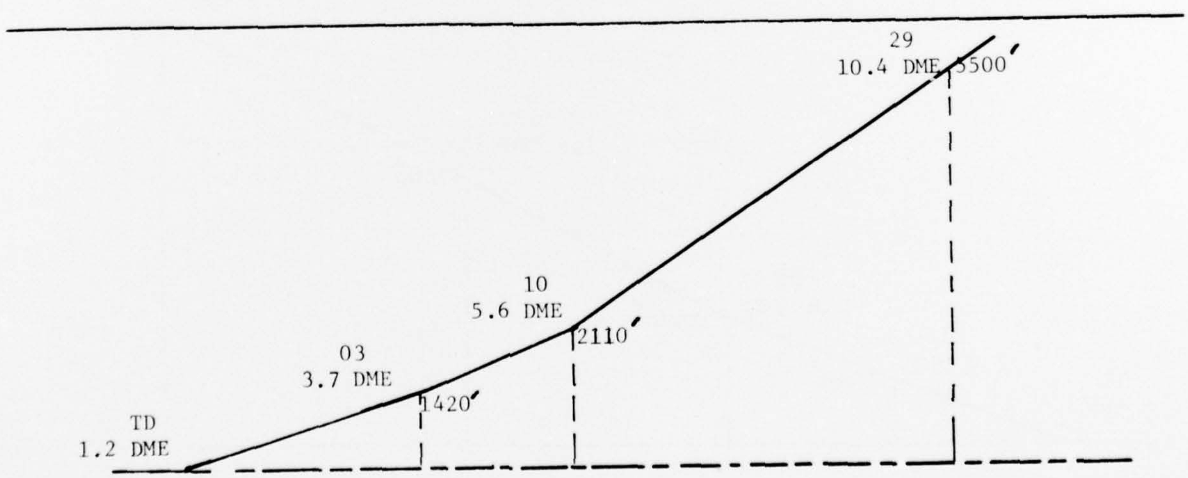




PROFILE 5

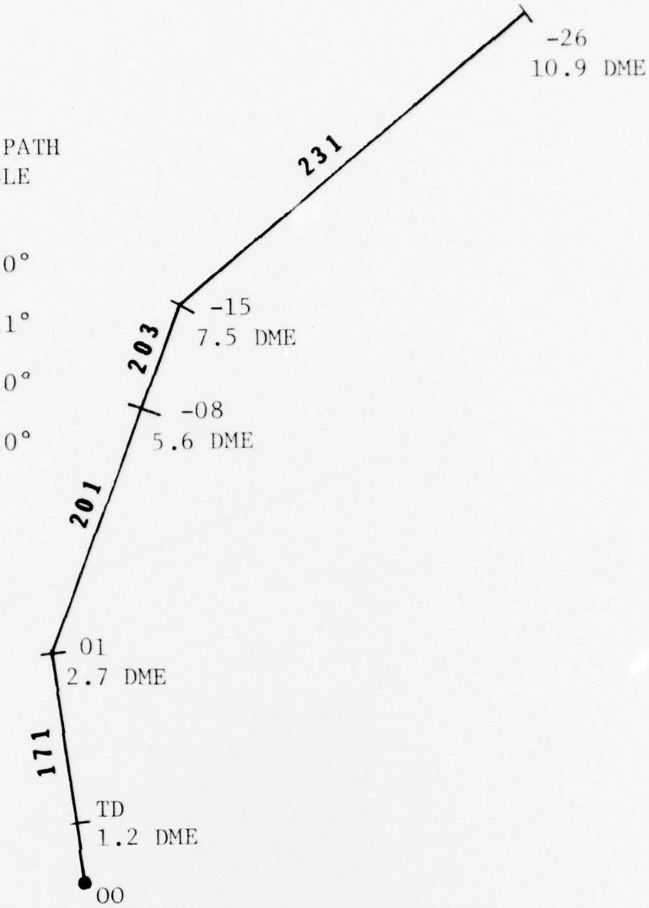
WAYPOINT SEQUENCE	GLIDE PATH ANGLE
29	
	6.0°
10	
	3.0°
03	
	3.0°
00	

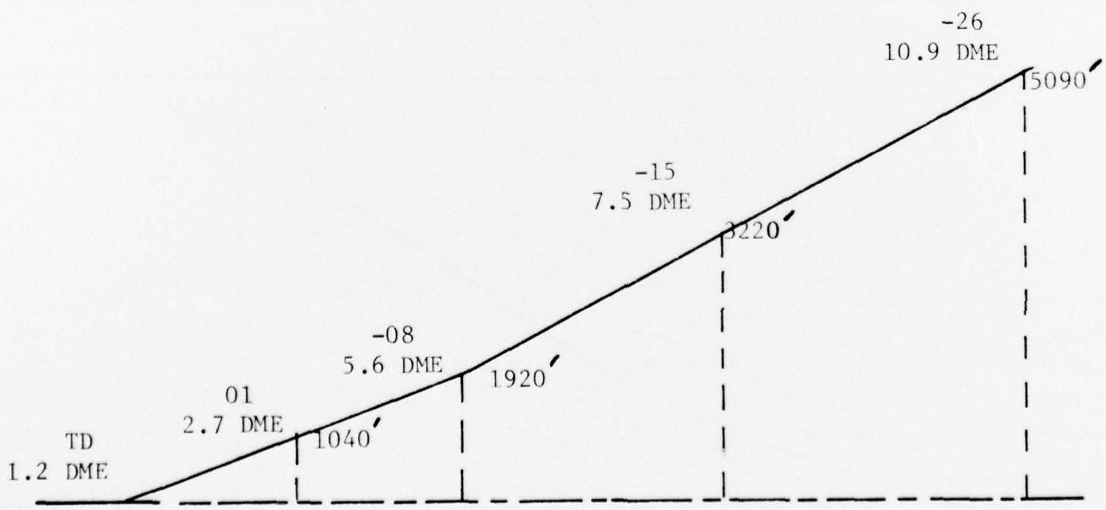




PROFILE 6

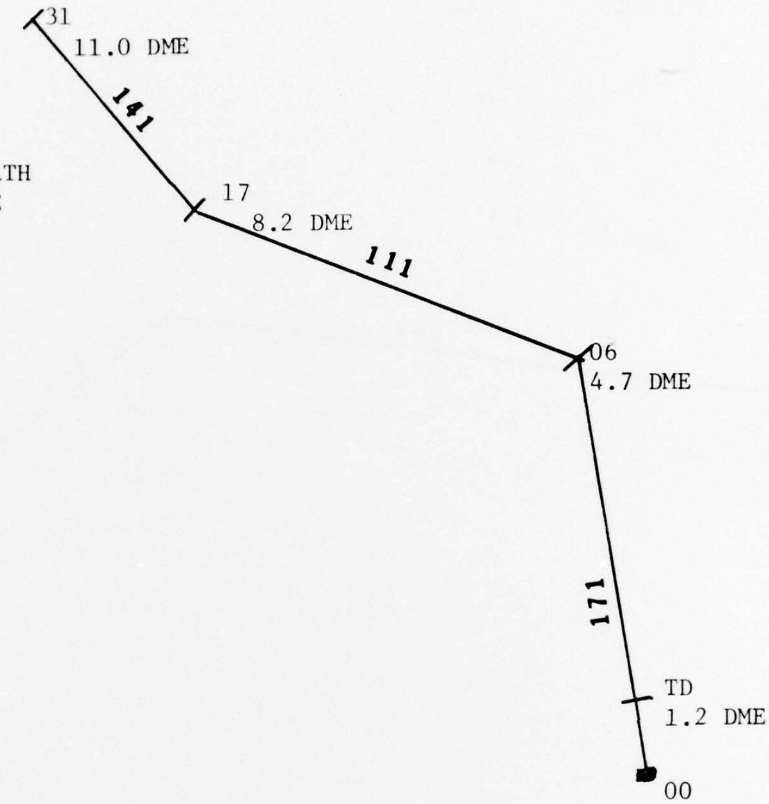
WAYPOINT SEQUENCE	GLIDE PATH ANGLE
-26	
	5.0°
-15	
	5.1°
-08	
	3.0°
01	
	3.0°
00	

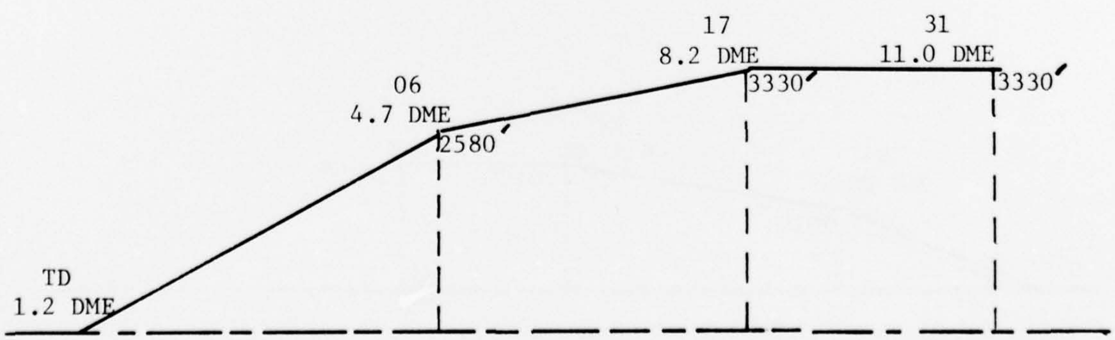




PROFILE 7

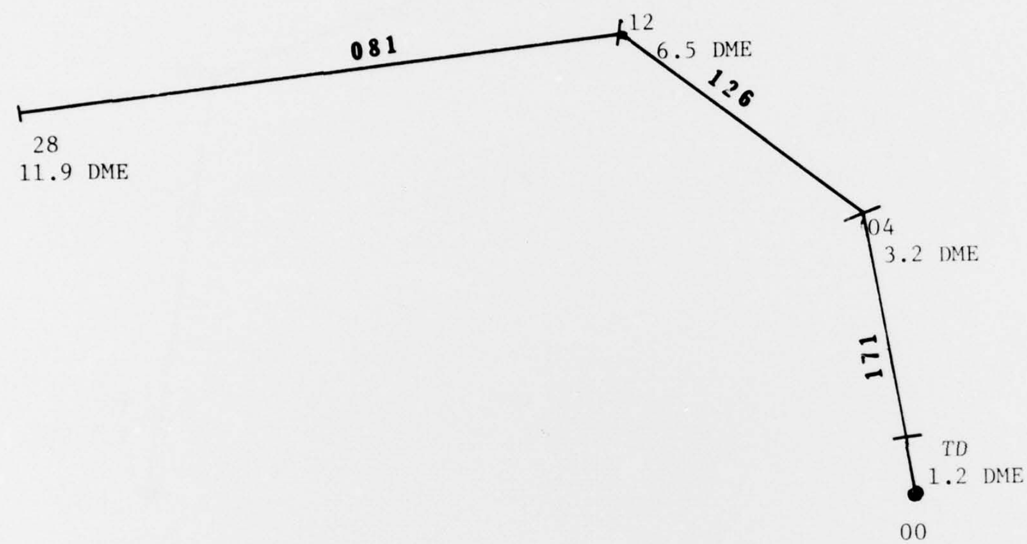
WAYPOINT SEQUENCE	GLIDE PATH ANGLE
31	
	0°
17	
	1.6°
06	
	5.0°
00	

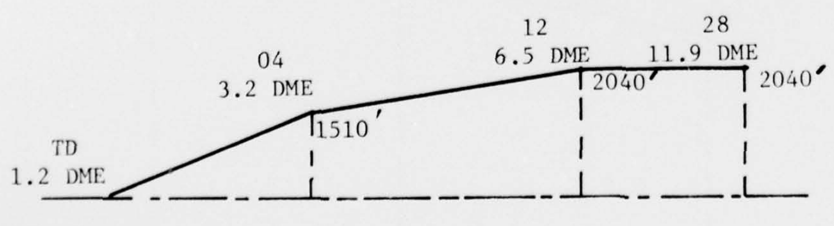




PROFILE 8

WAYPOINT SEQUENCE	GLIDE PATH ANGLE
28	
	0°
12	
	1.4°
04	
	4.1°
00	





APPENDIX D

MLS QUESTIONNAIRES

MLS END OF STUDY QUESTIONNAIRE

1. Do you feel that the dynamics simulation environment encountered in this experiment permits you to make a valid judgement regarding the feasibility of making instrument approaches in the MLS environment?

2. Given accurate information, which profile did you find the most difficult to fly? Why?

3. Given accurate information, which profile did you find the easiest to fly? Why?

4. What potential problems do you see in using the present simulator configuration to fly the given profiles?

MLS POST MISSION QUESTIONNAIRE

Name:__________________________

Date:__________________________

Mission:________________________

Profiles:_______________________

Yes No 1. Did you have any difficulty in capturing the desired course? Comment.

Yes No 2. Did you have any difficulty in capturing the desired glide slope? Comment.

Yes No 3. Did you have any difficulty in maintaining your horizontal orientation with reference to the runway? Comment.

Yes No 4. Did you encounter any difficulty in tracking the computed course using the bank steering bar or the CDI? Comment.

Yes No 5. Did you encounter any difficulty in tracking the computed glide slope using the pitch steering bar or the G/S indicator? Comment.

Yes No 6. At any time did you detect that the computed course did not accurately coincide with the prescribed course as shown on the approach plate? Comment.

7a. If the answer to Question #6 was "yes", then on which profile and by what means did you detect the discrepancy?

Yes No

8. At any time did you detect that the computed glide slope did not accurately coincide with the prescribed glide slope as shown on the approach plate? Comment.

9a. If the answer to Question #8 was "yes", then on which profile and by what means did you detect the discrepancy?

9b. Could you take any corrective action?

10. Given the present system and displays, rate how confident you would be with regard to executing a safe approach and landing.

Very unsure Very confident

Comment.

11. Do you have any recommended improvements to the present system and display?

APPENDIX E

Lateral and Vertical AAE Scores Per Profile

Profile Numbers	Segment	Lateral AAE Scores	1 Standard Deviation Unit; Lateral Scores	Vertical AAE Scores	1 Standard Deviation Unit; Vertical Scores
1	Crossleg	183.5	93.0	37.5	30.1
	Final	192.3	167.9	54.6	36.4
2	Crossleg	362.6	278.8	52.0	32.1
	Final	216.5	199.6	54.9	38.9
3	Crossleg	162.0	94.6	44.7	30.1
	Final	88.5	67.6	47.5	31.3
4	Crossleg	306.2	233.8	59.0	52.7
	Final	121.4	93.4	48.4	26.5
5	Crossleg	90.0	65.8	69.4	65.2
	Final	111.9	90.8	73.6	63.5
6	Crossleg	103.2	79.3	59.0	34.2
	Final	213.5	163.4	55.6	36.9
7	Crossleg	151.2	86.4	70.9	71.9
	Final	144.1	138.1	76.6	94.1
8	Crossleg	168.6	117.4	60.9	74.1
	Final	163.5	151.4	92.2	88.5

APPENDIX F

POST MISSION QUESTIONNAIRE

CONFIDENCE RATING RESULTS

Subject	S1	S2	S3	S4	S5	S6	S7		
Average	4.1	8.1	4.5	8.4	7.6	8.3	4.0		
Subject	S8	S9	S10	S11	S12	S13	S14		
Average	5.6	1.3	4.5	8.9	4.5	4.9	8.8		
Mission	I	II	III	IV	V	VI	VII	VIII	AVG.
Average	5.3	5.5	5.9	6.2	6.5	6.7	6.4	6.5	6.0

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